JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 1446:2020

STANDARD FOR SAFETY

Systems of Insulating Materials – General

Approved American National Standard
ANSI/UL 1446-2020

Standards Council of Canada
Conseil canadien des normes

SCC FOREWORD

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UL Standard for Safety for Systems of Insulating Materials – General, ANSI/CAN/UL 1446

Eighth Edition, Dated November 13, 2019

Summary of Topics

This revision of ANSI/UL 1446 dated November 19, 2020 has been issued to reflect the latest ANSI and SCC approval dates, and includes requirements for defined life thermal aging test; Section 3, 5.6A, 5.6B, 5.14A, Section 7A

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated May 22, 2020.

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ANSI/CAN/UL 1446:2020

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November 13, 2019

This ANSI/UL Standard for Safety consists of the Eighth Edition including revisions through November 19, 2020.

The most recent designation of ANSI/UL 1446 as an American National Standard (ANSI) occurred on July 1, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on November 19, 2020.

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Preface

This is the Eighth Edition of the ANSI/CAN/UL 1446 Standard for Systems of Insulating Materials – General.

UL is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 1446 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

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This Edition of the Standard has been formally approved by the UL Standards Technical Panel (STP) on Insulating Systems, STP 1446.

This list represents the STP 1446 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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INTRODUCTION

1 Scope

1.1 These requirements cover test procedures to be used in the evaluation of Class 120(E) or higher electrical insulation systems (EIS) for use in the United States, and Class 130(B) or higher EIS for use in Canada, where the thermal factor is the dominating aging factor. These requirements also cover the investigation of the substitution of non-electrical insulating materials (NIM) components of insulation in a previously evaluated insulation system and also the test procedures to be used in the evaluation of magnet wire coatings, magnet wires, and varnishes.

1.2 These requirements for the evaluation of an EIS do not establish thermal ratings for/or alter established thermal ratings for individual components.

1.3 These requirements do not cover insulation systems exposed to radiation or operating in oils, refrigerants, soaps, or other media that potentially degrade insulating materials.

1.4 When any performance aspect of an end-product requirement is not covered by this standard, the applicable standard shall be used.

1.5 These requirements do not cover electrical insulation systems where transient overvoltages or partial discharge are present. Such electrical insulation systems shall be evaluated to the appropriate standard for the application. Such standards include, but are not limited to the following:

a) IEEE C57.12.60;

b) IEC 60034-18-31; or

c) IEEE 1776.

2 Units of Measurement

2.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

3 Normative References

3.1 The following standards are referenced in this standard, and portions of these referenced standards may be essential for compliance. Electrical insulation systems covered by this standard shall comply with the referenced installation codes and standards as appropriate for the country where the electrical insulation system is to be used. When the electrical insulation system is intended for use in more than one country, the electrical insulation system shall comply with the installation codes and standards for all countries where it is intended to be used.

ASTM Standards

ASTM D1676, *Standard Test Methods for Film-Insulated Magnet Wire*

ASTM D1932, *Standard Test Method for Thermal Endurance of Flexible Electrical Insulating Varnishes*

ASTM D2307, *Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire*

ASTM D2519, *Standard Test Method for Bond Strength of Electrical Insulating Varnishes by the Helical Coil Test*

ASTM D3145, *Standard Test Method for Thermal Endurance of Electrical Insulating Varnishes by the Helical Coil Method*

ASTM D3251, *Standard Test Method for Thermal Endurance Characteristics of Electrical Insulating Varnishes Applied Over Film-Insulated Magnet Wire*

ASTM D5374, *Standard Test Methods for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation*

ASTM D5423, *Standard Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation*

ASTM D5642, *Standard Test Method for Sealed Tube Chemical Compatibility Test*

ASTM E178, *Standard Practice for Dealing with Outlying Observations*

CSA Standards

CSA C22.2 No. 0.17, *Evaluation of Properties of Polymeric Materials*

IEC Standards

IEC 60034-18-31, *Rotating Electrical Machines – Part 18-31: Functional Evaluation of Insulation Systems – Test Procedures for Form-Wound Windings – Thermal Evaluation and Classification of Insulation Systems Used in Rotating Machines*

IEC 60172, *Test Procedure for the Determination of the Temperature Index of Enamelled and Tape Wrapped Winding Wires*

IEC 60317, *Specifications for Particular Types of Winding Wires*

IEC 60455-2, *Resin Based Reactive Compounds Used for Electrical Insulation – Part 2: Methods of Test*

IEC 60455-3, *Resin Based Reactive Compounds Used for Electrical Insulation – Part 3: Specifications for Individual Materials*

IEC 60493-1, *Guide for the Statistical Analysis of Ageing Test Data – Part 1: Methods Based on Mean Values of Normally Distributed Test Results*

IEC TR 60493-2, *Guide for the Statistical Analysis of Ageing Test Data – Part 2: Validation of Procedures for Statistical Analysis of Censored Normally Distributed Data*

IEC 60505, *Evaluation and Qualification of Electrical Insulation Systems*

IEC 60851, *Winding Wires − Test Method*

IEC 61033, *Test Methods for the Determination of Bond Strength of Impregnating Agents to an Enamelled Wire Substrate*

IEC 61857-1, *Electrical Insulation Systems – Procedures for Thermal Evaluation – Part 1: General Requirements – Low-Voltage*

IEC 61857-21, *Electrical Insulation Systems – Procedures for Thermal Evaluation – Part 21: Specific Requirements for General-Purpose Models – Wire-Wound Applications*

IEC 61858-1, *Electrical Insulation Systems – Thermal Evaluation of Modifications to an Established Electrical Insulation System (EIS) – Part 1: Wire-Wound Winding EIS*

IEC 61857-31, *Electrical Insulation Systems – Procedures for Thermal Evaluation – Part 31: Applications With A Designed Life of 5 000 h or Less*

IEEE Standards

IEEE 1, *Recommended Practice – General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation*

IEEE 99, *Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment*

IEEE 101, *Guide for the Statistical Analysis of Thermal Life Test Data*

IEEE 1776, *Recommended Practice for Thermal Evaluation of Unsealed or Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-Insulated Stator Coils for Machines Rated 15 000 V and Below*

IEEE C57.12.60, *Test Procedure for Thermal Evaluation of Insulation Systems for Dry-Type Power and Distribution Transformers, Including Open-Wound, Solid-Cast, and Resin-Encapsulated Transformers*

NEMA Standards

NEMA MW 1000, *Magnet Wire*

UL Standards

UL 746A, *Polymeric Materials – Short Term Property Evaluations*

UL 746D, *Polymeric Materials – Fabricated Parts*

4 References

4.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

4.2 IEC test methods are the preferred test methods with the ASTM methods presented as technically equivalent except where noted in Table 4.1. If a designation for a test method is followed by an alternate or equivalent designation, in [brackets], the latter method can be considered technically equivalent, though not necessarily identical, and might yield somewhat different numerical test results.

Table 4.1
Test methods

ASTM Standards
ASTM D1676
ASTM D2307
ASTM D2519
ASTM D3145
ASTM D3251
ASTM D5642
ASTM E178
IEC Standards
IEC 60172 [ASTM D2307]
IEC 60317 (all parts) [ASTM D1676]
IEC 60455-2
IEC 60455-3 (all sheets for individual resins) [ASTM D3251]
IEC 60493-1
IEC TR 60493-2 [ASTM E178]
IEC 60505
IEC 60851 (all parts)
IEC 61033 [ASTM D2519]
IEC 61857 (all parts)
IEC 61858-1 [ASTM D5642]
IEEE Standards
IEEE 1
IEEE 99
IEEE 101
NEMA Standards
NEMA MW 1000

5 Glossary

5.1 For the purpose of this standard, the following definitions apply:

5.2 APPARENT THERMAL INDEX – The unadjusted thermal index of an insulation system derived from a regression analysis of that system's thermal aging data, usually higher in value than the system's rated temperature class.

5.3 CATALYST – A substance that alters (usually increases) the rate at which a reaction occurs without being consumed into the reaction.

5.4 CURING AGENT – A substance or mixture of substances that promote or control the reaction process and is consumed in the reaction.

5.5 CYCLE – A time period of heat exposure, which is used to induce deterioration at the specific aging temperature, followed by conditioning and diagnostic testing.

5.6 DEAD METAL – Metallic part that is at no electrical potential. With respect to the requirements in this Standard, dead metal parts are to be considered the same as if they were at ground potential.

5.6A DEFINED LIFE – The number of hours the EIS is suitable for use at the desired temperature class as specified in Table 7.2.

5.6B DESIGNED SERVICE LIFE – The actual operational time of the device employing the EIS, which may be in continuous or intermittent operation, as determined by the end use product manufacturer for the expected life of the product at a thermal class rating as specified in Table 7.2.

5.7 EIS – ELECTRICAL INSULATION SYSTEM – Electrical insulating structure containing one or more electrical insulating materials (EIM) together with associated conducting parts employed in an electrotechnical device.

5.8 ELECTRICAL INSULATION SYSTEM CLASS – An agreed upon classification; refer to 7.5.5(c).

5.9 GENERAL PURPOSE MODEL (GPM) – A unit constructed in accordance with the specifications in IEC 61857-1, with specific description of the GPM in IEC 61857-21, except that:

a) The slot assembly, comprised of both inner and outer slot plates, shall be constructed of stainless steel; and

Exception: When stainless steel is not able to be used due to difficulty in material adhesion, such as an epoxy coating, or similar problem, cold rolled steel is able to be used.

b) The magnet wire shall be 0.82 mm^2 (18 AWG) unless unavailable, in which case any wire size 0.20 mm^2 (18 AWG – 24 AWG) is able to be used.

5.10 GEOMETRIC MEAN – The n^{th} root of the product of n values. Mathematically will result in the same value as the log average.

5.11 LOG AVERAGE – The antilog of the quotient, defined as the sum of the logs as the dividend, divided by the number of values as the divisor. Preferred method for calculating life but mathematically will result in the same value as the geometric mean.

5.12 SAMPLE – Actual electrotechnical products, components thereof, or non-functional models representing the product, e. g. general purpose model (GPM), used in the evaluation of an insulation system.

5.13 SYSTEM – An insulation system. See 5.7.

5.14 SYSTEM COMPONENTS – Grouped as follows:

a) ELECTRICAL INSULATING MATERIAL (EIM) (also known as Major Components) – The components of an insulation system that are relied upon to prevent a risk of electric shock or fire. Examples of this type of insulation include ground, interwinding, turn, encapsulant, and varnish. See Table 5.1.

b) NON-ELECTRICAL INSULATING MATERIALS (NIM) (also known as Minor Components) – The components of an insulation system that are used typically in mechanical or thermal conduction capacities, and are not relied upon to prevent risk of fire or electric shock. See Table 5.1.

5.14A THERMAL ENDURANCE RATING – The defined life in hours of the EIS at the selected temperature class as specified in Table 7.2.

Table 5.1
Common EIM and NIM

Type	EIM	NIM	Definition/[Comments]
Balancing Compound (Motor Term)	–	X	A material applied to a rotor to reduce vibration.
Bobbin or Core Tube (Transformer Term)	X	X	The form around which the conductor is wound. [It is an EIM when it is the sole insulation between windings and grounded or dead metal. It is a NIM when it is always provided with a supplemental EIM insulation between isolated windings and grounded or dead metal.]
Crossover Insulation	–	X	Component providing isolation between the magnet wire at the point where it enters the coil and all subsequent layers or turns of wire to the winding to which it is connected and to all other winding turns or layers. This insulation may be in sheets, films, film tapes or it may be of material inclusive to the molded coil form designed for that purpose.
Enameled Magnet/Winding Wire	X	–	Wire coated with an insulation of cured polymeric resin.
Encapsulant	X	–	An EIM, usually a molding material which is typically cast or injection molded around the electrical insulation system (EIS) and is intended to electrically insulate and protect the EIS. An encapsulant is a material used to separate the windings from components at a different voltage or from dead metal parts and also provides other safety protection. For example, be separating the windings from the metal stack. Encapsulated devices do not employ supplementary surrounding shells hence the encapsulant may function as an electrical enclosure.
End Spider (Motor Term)	X	X	The material provided between rotor laminations and the winding as it passes from slot to slot. [It is an EIM when no supplemental EIM insulation is provided between conductors and ground. It is a NIM when provided with required ground insulation or a 0.8 mm (1/32 in) minimum air space between conductors and the end spider.]
Filament Winding	X	–	Windings constructed of the type of wire typically used as lead wires.
Fully Insulated Wire (FIW)	X	–	Enameled magnet/winding wire with sufficient build to provide Zero High Voltage Continuity Defects.
Ground Insulation	X	–	The electrical insulation between the conductor and grounded or dead metal.
Integral Ground	X	–	A coating, such as epoxy, that is fused directly to the grounded or dead metal core and serves as ground insulation.
Interwinding Insulation (Transformer Term)	X	–	An EIM placed between individual windings. [Does not apply to material used between series-parallel windings in multi-voltage transformers where the coils are physically separated by minimum safety spacing.]
Layer Insulation (Transformer Term)	–	X	The material interleaved between successive layers of an insulated conductor in the same winding. [Used in a mechanical application only, and does not serve as electrical insulation.]
Lead Wire	–	X	The insulated wire attached to the end of a winding to connect the device to a circuit. [It is identified as part of the system when its insulation enters the confines of the winding or outer wrap. When used to form a magnetic winding, it is identified as a filament winding.]
Litz wire (Transformer Term)	X	X	A bundle of magnet wire bound together by a strand of magnet wire or another material (dacron, fiberglass, aramid fiber, or similar materials). The magnet wire portion of a Litz wire is considered an EIM component. The non-wire portion wrapped or extruded around the bundle and/or core material is considered a NIM component. [Typically used in high frequency transformers.]
Magnet/Winding Wire	X	–	An insulated conductor used in wound coils to provide a magnetic field.
Non-enameled Magnet/Winding Wire	X	–	Magnet/Winding Wires that are insulated with materials that are not applied via solvent removal and the curing of polymeric resins.

Table 5.1 Continued on Next Page

Table 5.1 Continued

Type	EIM	NIM	Definition/[Comments]
Outer Wrap	X	X	The material that is placed over the final layer of winding. [It is an EIM when there is not a 0.8 mm (1/32 in) minimum air gap separating it from grounded or dead metal.]
Phase Insulation (Motor Term)	–	X	An EIM placed between adjacent windings of a multi-phase rotating device where coils are in direct contact with coils are different voltages and/or dead metal parts.
Potting Compound	–	X	A NIM which is placed in a permanent housing or enclosure where the housing or enclosure (potting shell) remains as part of the construction of the component. The potting compound functions for purposes such as holding components in place, providing a means for heat dissipation, or other NIM functions. If the potting compound was not part of the product the component could still function properly.
Potting Shell	–	X	The enclosure that holds the potting compound and insulation system.
Securement Tape	–	X	Tapes used in mechanical applications only, and have not been evaluated as electrical insulation within the system. Also known as "anchor tape".
Shaft Tube or Shaft Hugger (Motor Term)	X	X	The insulating tube between the shaft and windings. [It is an EIM when it relied upon to provide the insulation between the conductors and shaft. It is a NIM when provided with either required EIM insulation or a 0.8 mm (1/32 in) minimum air space, between conductors and the shaft.]
Sleeving and Tubing	–	X	Materials that typically are used to cover electrical connections.
Slot Liner (Motor Term)	X	–	The material used in the channels of a rotor or stator that is relied upon to insulate the winding from grounded or dead metal parts.
Spacers, Wedges and Topsticks	–	X	Materials that are used in a mechanical capacity within the device.
Tie Cord	–	X	Strings, cords or cable ties that are used for mechanical securement.
Touch-Up or Overcoat Varnish	–	X	A material typically applied over the insulating varnish for aesthetic purposes.
Turn Insulation	X	–	Any material relied upon to electrically isolate adjacent conductors. [For example: magnet/winding wire insulation, sheet materials and filament windings' insulation.]
Varnish and Impregnating Resin	X	X	A liquid insulator which coats or impregnates the coil and is then cured. [It is an EIM component when a varnish was present in the original full thermal aging where it may have contributed to the overall performance of the system.]
Window Insulation (Transformer Term)	X	X	A material used to supplement an air gap between a winding and grounded or dead metal. [It is identified as EIM when the air gap separating the insulation from the grounded or dead metal is less than 0.8 mm (1/32 in).] Also known as "core window insulation".
Note: X means this type of material complies with the EIM and/or NIM designation.			

PERFORMANCE CRITERIA

6 Insulation Systems

6.1 General

6.1.1 Electrical insulation systems shall be evaluated following the guidelines as set forth in IEC 60505. A full thermal aging program, in conjunction with a qualified reference insulation system, test protocol and sample requirements, is specified in Section 7, Electrical Insulation Systems – Full Thermal Aging for this purpose.

6.1.2 An insulation system shall be investigated to determine whether the components within an insulation system are compatible and to establish a temperature class for the system.

6.1.3 Insulating materials having different assigned temperature classes are able to be combined to form an insulation system having a temperature class that is higher or lower than that of any of the individual components.

6.1.4 The compatibility of an insulating material with other materials in the same insulation system shall be investigated to determine whether thermal aging of such components makes the system susceptible to unacceptable deterioration that inhibits intended performance in normal service at the assigned temperature class of the system.

6.1.5 The compatibility of an EIS with one or more separate EIS in proximity to it shall be investigated when the EIS are in direct contact with each other. For example, a transformer primary coil that is wound directly over and in contact with the transformer secondary coil. The compatibility of two or more separate EIS used within a single device is not required when at least a 3.05 mm (0.125 in) air space separates them.

6.1.6 Constructional features, such as mechanical and electrical properties of lead-wire insulation, including thickness and type, thickness and dielectric strength of a component, electrical spacings, and operating temperatures, shall be evaluated in the end-use product.

6.2 EIS components

6.2.1 EIS components include magnet/winding wire, ground insulation, encapsulant, phase insulation, varnish/impregnating resins, wedges, tapes, lead wire, tie cord, sleeving, and all similar parts.

6.2.2 For the purpose of documenting materials and facilitating component substitutions, information concerning insulation system components shall be obtained prior to testing. The information shall include:

a) Manufacturers' name and catalog numbers or the equivalent;

b) Thicknesses of EIM components (where appropriate), including the thickness of each layer of a laminate; temperature classes, when appropriate; the temperature class and style or type designation of each type of lead wire; and

c) Other appropriate information.

6.2.3 Bobbins intended for use as ground or interwinding insulation that are molded from polymeric materials shall comply with UL 746D or CSA C22.2 No. 0.17.

6.2.4 When utilized in a full thermal aging program, sheet materials used as turn insulation in bare-conductor configurations shall be evaluated in the same manner as magnet wire.

6.2.5 A coating resin intended for use as integral ground insulation shall comply with the requirements specified in Section 7, Electrical Insulation Systems – Full Thermal Aging.

6.2.6 A lead wire having a temperature rating that is more than 5°C (9°F) lower than the temperature rating of the insulation system in which it is connected shall be compatible and shall be separated from the windings by a barrier or envelope of a material compatible with the system. The temperature rating of the lead wire shall not be less than that specified in Table 6.1.

Exception: Lead wire that has been evaluated for use in the insulation system by means of at least a one temperature thermal aging program is not required to comply with this requirement. See SA7.1.1(e) and SA7.2.1(e).

Table 6.1
Lead wire temperature ratings

Insulation system class	Minimum lead-wire temperature rating °C	(°F)
120(E)	90	(194)
130(B)	90	(194)
155(F)	125	(257)
180(H)	150	(302)
200(N)	180	(356)
220(R)	200	(392)
240(S)	220	(428)

6.2.7 The use of metal foil or an adhesive backed metal foil tape used as shielding in an insulation system requires a suitable ground or interwinding insulation between the metal foil and all windings.

6.2.8 The use of metal foil or an adhesive backed metal foil tape used to make a winding in an insulation system requires a suitable turn insulation between consecutive turns.

6.2.9 Any material or component existing outside the outer wrap of the device and/or not in direct contact with the winding insulation is considered not to be part of the EIS.

PERFORMANCE TESTS

7 Electrical Insulation Systems – Full Thermal Aging

7.1 General

7.1.1 Representative samples of the candidate insulation system and a qualified reference insulation system shall be subjected to a full thermal aging, consisting of a minimum of three temperatures. At each of the aging temperatures, samples shall be subjected to a cycling program, undergo diagnostic testing, and the data from all temperatures shall be analyzed to determine a thermal class rating by comparison to the reference system.

7.1.2 Additional components not present in the thermally aged samples shall be added by methods outlined in Supplement SA.

7.2 Samples

7.2.1 Test samples of either an operating part or a representative construction shall include all EIM components, and any additional NIM components, assembled to represent the intended end-use insulation system. Test samples of an open-type (non-encapsulated) system are not representative of an encapsulated system. Materials acting in a ground, interwinding, or encapsulating capacity shall be tested in the minimum thickness. When subsequent thickness reduction is required, see SA6.3.

7.2.2 Test samples representative of an encapsulated system shall be subjected to a thermal aging program per Section 7, Electrical Insulation Systems – Full Thermal Aging.

7.2.3 The winding configuration of the intended end-use insulation system is to be represented in the test samples. Tests on a random wound construction are determined to be representative of other winding configurations such as layer wound or precision wound, and not the opposite. Lead wires are to be additionally protected beyond where they emerge from the windings, so that contact with sample frames does not occur. The protection is to be an inert material, such as unimpregnated glass-fiber tubing, that is not able to interact with the insulation system.

7.2.4 The number of samples in a group for each aging temperature shall not be less than:

a) Six samples of an operating part containing the insulation system;

b) Ten samples of a non-functional aging specimen representative of the insulation system; or

c) Ten samples of a relay or solenoid coil.

7.2.5 As test results are dependent upon variations in test conditions, a reference insulation system shall also be tested in the same manner as the candidate insulation system to correlate results of the thermal aging test program to intended service conditions.

7.2.6 To qualify as a reference/candidate pair, the following conditions must be met:

a) The reference system shall be a unique combination of materials that has been previously thermally aged.

Exception: When some of the original materials are no longer available, they are to be deleted or substituted with other materials that are agreed by all interested parties to be similar.

b) The reference system shall have field-service history of operation supporting the specific insulation system temperature class;

c) The physical construction of the candidate shall be the same as the reference insulation system (i. e., general purpose model to general purpose model (GPM), solenoid coil to solenoid coil, encapsulated coil to encapsulated coil, etc.);

d) The magnet wire gauge size of the turn to turn insulation of the candidate shall be within 0.2 mm diameter or 3 AWG sizes for bare conductor of the reference insulation system;

e) The turn to turn wire insulation build of the candidate system shall be equal to or thinner than the reference.

f) A reference insulation system shall be tested concurrently with any candidate insulation system; and

g) The reference insulation system shall be thermally aged in the same oven Type as the candidate insulation system in accordance with 7.3.1.1.

Exception No. 1: When all interested parties agree, reference data is able to be used for five years, following completion of the reference system's aging, when neither the equipment, test methods, nor test conditions have changed in the interim.

Exception No. 2: When a reference is not agreed upon by all parties, a fixed correlation time of 40,000 h shall be used.

h) All parties shall agree upon the testing protocol before testing can begin.

7.2.7 In order to detect faulty sample configurations or individual defective samples, all samples shall be screened before thermal aging begins by subjecting all samples to one full exposure cycle, except for the oven aging, then subjected to the appropriate diagnostic tests in accordance with 7.4. Samples that do not meet the requirements in the diagnostic tests in 7.4 shall be eliminated from the test program and shall be replaced with usable samples such that the number of samples remains in compliance with 7.2.4.

7.3 Exposures

7.3.1 Heat aging

7.3.1.1 The thermal-aging ovens that are used in the aging program are to be calibrated using the methods in ASTM D5374 and comply with ASTM D5423 for Type I (5 – 20 air changes per hour) or Type II (100 – 200 air changes per hour) ovens, primarily with respect to Rate of Ventilation, Set Temperature, Temperature Variation and Thermal Lag Time. The use of either Type I or Type II is acceptable provided the reference and candidate samples are aged in the same Type.

7.3.1.2 The spread between aging temperatures is to be not less than 10°C (18°F) in order to minimize the effect of small errors in measuring and controlling these temperatures.

7.3.1.3 The aging temperatures shall be specified with the understanding that the lowest test temperature shall result in a log average or geometric mean time to end of test-life of at least 5000 hours and the highest test temperature shall result in a log average or geometric mean time to end of test-life of at least 100 h. An aging temperature that is too high sometimes results in non-linear data, potentially invalidating that point, requiring testing at an additional lower temperature in order to obtain linear data.

7.3.1.4 Preliminary screening tests are able to be used as an aid in specifying the initial test temperatures. When screening data meets the criteria specified in 7.3.1.3, it is capable of being used in the final data analysis.

7.3.1.5 For each aging temperature, there is to be an assigned initial aging cycle period, for example, 24 – 72 h for the highest temperature; 48 – 168 h for the next lower temperature; 96 – 336 h for the next lower temperature; and 168 – 672 h for the lowest temperature.

7.3.1.6 With reference to 7.3.1.5, the initial aging cycle period is able to be increased (for example, doubled) when less than one-half of the samples reach end of test-life after 8 cycles or decreased (for example, halved) when one-third of the samples reach end of test-life within 3 cycles.

7.3.1.7 For samples that are continuously energized and, as a result, are self-heating:

a) The temperature of a single sample or a sample set shall not vary by more than ±2°C (±3.6°F) from the recorded temperature. The temperatures are to be measured by the change-of-resistance method or by thermocouples located on the samples. The aging period is determined to begin when temperature stability is obtained and the temperatures are within tolerance. These temperatures are to be checked at least twice each thermal aging cycle, and not less than once weekly; and

b) A means of detecting end of test-life during the thermal aging test shall be provided, either with or without a means of automatically de-energizing these samples.

7.3.2 Mechanical stress

7.3.2.1 Following the heat aging phase of the cycle, a specific procedure for vibration conditioning is to be determined and agreed upon by all interested parties. Once this procedure has been established, consistency is to be maintained. Typical vibration conditioning procedures are specified in 7.3.2.2 – 7.3.2.5. Externally applied vibrations are to be induced by a laboratory grade vibrator having accurately controlled adjustments at the specified levels.

7.3.2.2 A non-functional specimen is to be stabilized at ambient temperature, vibrated for 1 h at a frequency of 60 Hz and an acceleration of 14.7 m/s^2 (48.3 ft/s^2), resulting in a peak-to-peak displacement of 0.20 mm (0.008 in).

7.3.2.3 A transformer is to be stabilized at ambient temperature, vibrated for 60 min at a frequency of 60 Hz and an acceleration of 14.7 m/s^2 (48.3 ft/s^2), resulting in a peak-to-peak displacement of 0.20 mm (0.008 in).

7.3.2.4 A functioning motor is to be stabilized at ambient temperature then subjected to mechanical stress by one of the following methods:

a) Reversed or started and stopped 250 times per cycle;

b) The same as a non-functional specimen in 7.3.2.2; or

c) The same as a transformer in 7.3.2.3.

7.3.2.5 A solenoid coil is to be stabilized at ambient temperature then subjected to mechanical stress by one of the following methods:

a) Assembled into a valve and operated 1,000 times at ambient temperature;

b) An appropriate impact test;

c) The same as a non-functional specimen in 7.3.2.2; or

d) The same as a transformer in 7.3.2.3.

7.3.3 Cold shock

7.3.3.1 The temperature of the cold chamber is to be controlled within ±5°C (±9°F).

7.3.3.2 When, based on the application, cold shock is part of the conditioning cycle, following the mechanical stress conditioning, samples are to be placed in the cold chamber, which has been stabilized to the temperature specified in Table 7.1. The temperature of the chamber and samples is to be monitored during the conditioning. Conditioning ends when the temperature of the sample stabilizes. Stabilization time varies with sample mass.

Table 7.1
Cold-shock temperatures

Application	Temperature, °C (°F)	
	Indoor use	Outdoor use
Motor	Not specified	Not specified
Coil other than a motor coil	0 (32)	-20 (-4)
Transformer	Not specified	-20 (-4)

7.3.4 Exposure to moisture

7.3.4.1 A laboratory grade humidity or condensation chamber, or equivalent, capable of maintaining the specified humidity and temperature levels is to be used.

7.3.4.2 Samples are to be conditioned for 48 h at 92 – 100% relative humidity for indoor use applications at not less than room ambient temperature. For equipment intended for outdoor use, the relative humidity is to be 100% with surface moisture present on each sample and the amount of moisture at all points on each sample is to be uniform. In either case, drops of water are to be prevented from falling from the top of the humidity chamber onto the samples. A heated top or a tent suspended in the humidity chamber over the samples is able to be used for protection.

7.4 Diagnostic tests – determination of end of test-life

7.4.1 After exposure to moisture as described in 7.3.4, and while the samples are still in the humidity chamber or immediately after removal, the test samples are to be subjected to the following tests to detect winding-to-winding, winding-to-ground, and turn-to-turn breakdowns which is considered the end of test-life. Dielectric voltages specified are usable to detect a material's end of test-life and shall not be used to establish a voltage rating for the system:

a) For a non-functional specimen representing an operating part, dielectric stresses of 600 V winding-to-winding and winding-to-ground, plus 120 V turn-to-turn are to be applied, each for 10 min. End of test-life shall be identified when a 0.75 A circuit breaker opens during either dielectric stress test.

b) For a solenoid or relay type non-energized coil, either a shorted turns tester or input measurements are to be used to detect turn-to-turn breakdown. A 10% increase in input current of an aged coil as compared to an unaged coil is an indication of turn-to-turn breakdown. The check of ground insulation is to consist of a dielectric stress winding-to-ground at a voltage of twice that of the coil's rated voltage plus 1,000 V. To determine the condition of outer wrap intended to be used as ground insulation, coils are to be stressed winding-to-ground through the core and the outer wrap by means of immersion in lead shot, wrapping in metallic foil, or some equivalent means. Care is to be taken to avoid breakdowns at slots, end turns, and bare edges, or such results are to be discounted in evaluating the data. The test voltage is to be applied for 10 min.

c) For operating part samples that are continuously energized at their intended voltage and as a result are self-heating, such as a solenoid, transformer, or motor, the testing to determine end of test-life shall be agreed upon prior to the start of testing. This testing is not prohibited from including, but not limited to, the opening of an overcurrent protective device, indiscriminate starting and stopping of the device, changes in the devices' insulation resistance or dielectric dissipation measurements, or changes in the direction of a motor's rotation. When end of test-life is detected, the time in hours to that point shall be taken as the accumulated thermal aging time.

7.4.2 To conduct the dielectric withstand test specified in 7.4.1(a) and 7.4.1(b) above, a test transformer having a capacity of at least 500 VA is to be used so that leakage current through the insulation system does not reduce the actual applied voltage below that indicated at the primary. However, a test transformer other than that specified is not prohibited from being used when the secondary potential of the test transformer is monitored during the test to determine that the required test voltages are not reduced due to leakage current.

7.4.3 The end of test-life for each sample shall be verified by repeating the dielectric stress test after the sample has been subjected to one additional complete cycle. The first detected and confirmed dielectric breakdown is considered the end of test-life for that sample.

7.4.4 With the exception of samples aged by self-heating, when the end of test-life has been verified the time in hours is to be recorded as the accumulated thermal aging time for the first determination of end of test-life minus one-half the time of the last oven aging cycle.

7.5 Analysis and evaluation

7.5.1 In evaluating the performance of an insulation system, each sample that has reached end of test-life shall be visually inspected. When a condition other than deterioration of insulation is attributed to the end of test-life, such as a winding burnout due to a rusted or locked movable part, or decomposition of a lead wire at a point remote from the system itself, the sample shall be omitted from the data set. When, after omitting these samples from the data set, there remains less than five values in the set, the entire data set shall be determined to be invalid.

7.5.2 The system test-life is a function of temperature. The Arrhenius equation defined in 7.5.3, which describes the temperature dependence of the velocity coefficient of chemical reactions, is able to be used to model the relationship between system test-life and temperature.

7.5.3 The Arrhenius equation is capable of being simplified by taking the natural logarithms in the following form:

$$\log_e K = \log_e A - \frac{E}{RT}$$

In which:

K is the specific rate of reaction

T is absolute temperature, Kelvin

E is the activation energy

R is the gas constant

Letting $Y = \log_e K$, $a = \log_e A$, $b = -E/R$, and $X = 1/T$, then $Y = a + bX$. This relates the two variables Y and X in the form of a linear equation, assuming a and b are constant. In order to convert to base (10) for calculation purposes, $\log_e K$ is changed to $\log_{10} K$ by dividing through both sides of the above equation by $\log_e 10$. The form of the equation remains unchanged.

7.5.4 This equation, as applied in this case, indicates that the logarithm (base 10) of system test-life (in hours) is a linear function of the reciprocal of the absolute temperature in Kelvin. The best fit of the slope and intercept of the straight line that relates these two variables shall be determined by the least-squares method of linear regression analysis. After the regression equations for both the candidate and the reference systems are determined and plotted, a comparison shall be made in order to establish the thermal class of the candidate insulation system.

7.5.5 The following steps shall be followed to determine the temperature class of a candidate system:

a) Determine the correlation time t_c in hours of the reference system as given by:

$$t_c = \exp_{10} \frac{M_c}{T_c + 273.15} + B_c$$

In which:

M_c is the slope of the reference system's regression equation

B_c is the ordinate intercept of reference system's regression equation

T_c is the apparent thermal index of the reference system in °C (see 5.2)

b) Determine the apparent thermal index T in °C of the candidate system from:

$$T = \frac{M}{\log_{10} t_c - B} - 273.15$$

In which:

M is the slope of candidate system's regression equation

B is the ordinate intercept of candidate system's regression equation

t_c *is the correlation time of reference system determined in (a)*

c) Assign the temperature class of the candidate system by recording the highest system temperature class (as given in Table 7.2) which does not exceed the apparent thermal index of the candidate system.

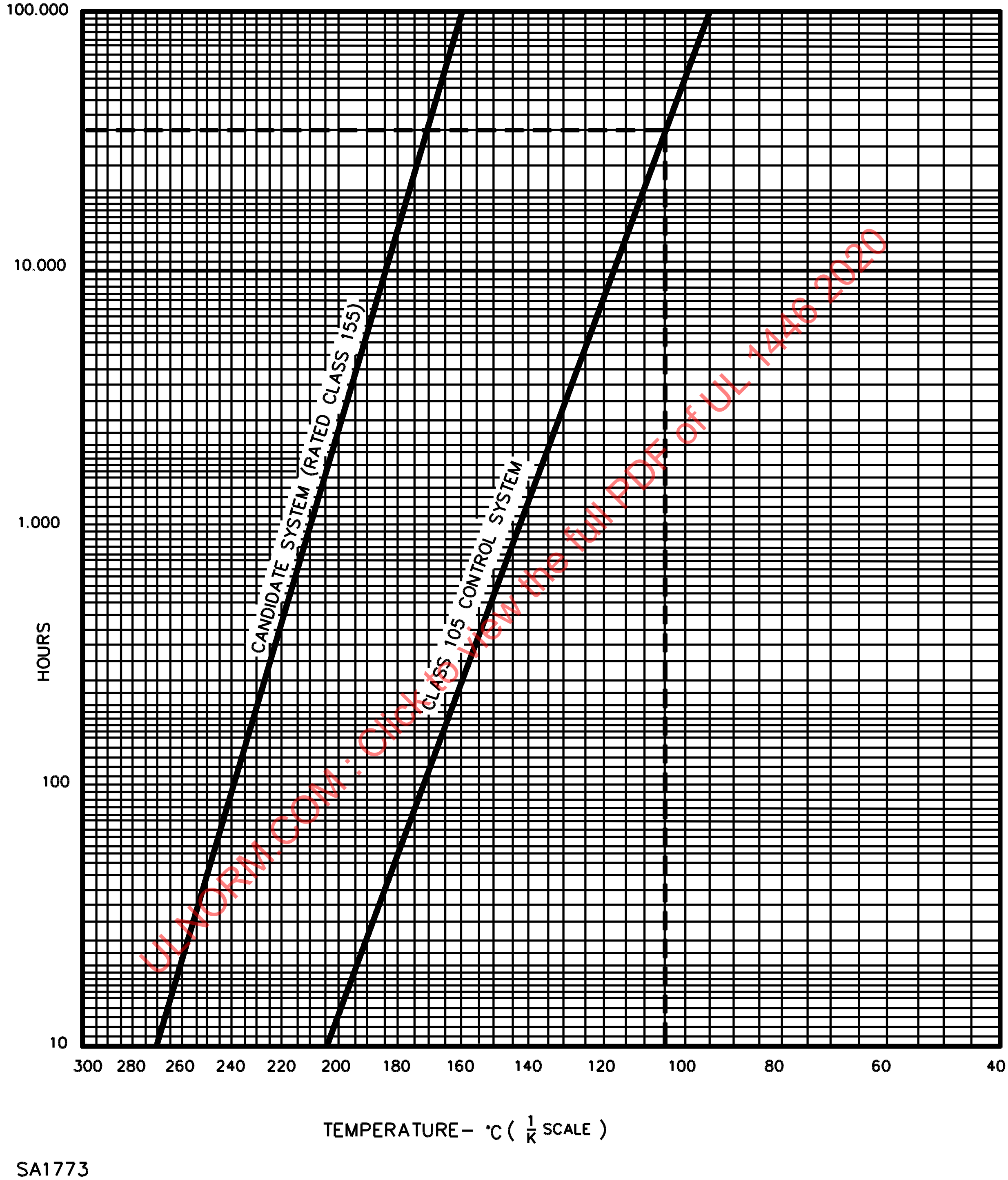
Table 7.2
Maximum hot-spot temperatures of insulation systems

System class		Maximum hot-spot temperature,	
US	**Canada**	**°C**	**(°F)**
120(E)	–	120	(248)
130(B)	B	130	(266)
155(F)	F	155	(311)
180(H)	H	180	(356)
200(N)	C	200	(392)
220(R)	C	220	(428)
240(S)	C	240	(464)
Over 240(C)	C	Over 240	(Over 464)

7.5.6 Figure 7.1 illustrates the regression lines obtained as the result of aging the reference and candidate systems at elevated temperatures. The time to reach end of test-life at each temperature was used to construct the time-temperature plots shown.

Figure 7.1

Determination of insulation systems temperature class



7.5.7 The reference system shown has a thermal index of 105°C (221°F). In this example, this known system shows a correlation time of 35,000 h when tested in the manner described in this program.

7.5.8 The time-temperature plot of the candidate system under investigation intercepts the 35,000-h line at an apparent thermal index temperature of 170°C (338°F). This system was then assigned a Class 155(F) temperature class (from Table 7.2), the highest class which does not exceed the 170°C apparent thermal index.

7A Electrical Insulation Systems – Defined Life Thermal Aging

7A.1 General

7A.1.1 For an EIS where the intended application has a designed service life of 5000 hours or less, representative samples of the candidate EIS shall be subjected to a thermal aging as outlined in IEC 61857-31.

7A.1.2 Additional components not present in the thermally aged samples shall be added by methods outlined in Supplement SA.

7A.2 Samples

7A.2.1 Test samples of the candidate insulation system shall be prepared and screened as outlined in 7.2, Samples, with the exception that no reference insulation system is required.

7A.3 Test procedure

7A.3.1 The test procedure and samples are the same as outlined in Section 7, Electrical Insulation Systems – Full Thermal Aging, with the exception of the number of test samples and aging test temperatures as specified in Procedure A, Procedure B and Procedure C below.

7A.3.2 Procedure A (One temperature aging) – Applications with a designed service life of 1500 hours or less shall utilize ten (10) test samples and the aging test temperature shall be 10°C (18°F) higher than the desired temperature class rating with an heat aging cycle of 168 hours accumulating a minimum of 1500 hours. If there are no sample failures 1500 hour will be achieved in 9 cycles.

7A.3.3 Procedure B (One temperature aging) – If the samples tested under Procedure A have exceeded 1500 hours, the testing may be continued in the same manner until all samples fail or 5000 hours of aging time is reached, whichever comes first.

7A.3.4 Procedure C (two temperature aging) – As an alternative to Procedures A and B for applications with a designed service life of 5000 hours or less to be evaluated at two (2) elevated temperatures. The higher test temperature shall utilize ten (10) test samples and are heat aged 30°C (54°F) to 35°C (63°F) higher than the desired temperature class rating with a heat aging cycle period between 24 – 72 h. The lower test temperature shall utilize ten (10) test samples and are heat aged 20°C (36°F) to 30°C (54°F) higher than the desired temperature class rating with a heat aging cycle period between 48 – 168 h.

7A.4 Analysis and evaluation

7A.4.1 For Procedure A and B, If there are no sample failures prior to achieving the Defined Service Life hours, then testing may be discontinued and the obtained hours of aging shall be used as the Defined Life. If samples fail during the test procedure, the failure time is reported for each of the samples as described in 7.4.4, and the average life of all samples is to be calculated as a geometric mean time for that temperature and shall be used as the Defined Life.

7A.4.2 For Procedure C, All samples tested at the higher aging temperature shall be aged to completion of end of test-life as described in 7.4.4 and the average life of all samples calculated as a geometric mean time. The lower aging temperature samples shall be aged to end of test-life as described in 7.4.4 with the average life of all samples calculated as a geometric mean time. The highest and lower test temperature geometric mean times shall be expressed as a linear function and the Defined Life is determined by intercepting the line at the desired temperature class. The Defined Life result shall be rounded down to the nearest 500 hour. The Defined Life shall not exceed 5000 hours.

Exception: Aging of the lower test temperature samples to end of test-life is not required if the accumulated hours for the lower test temperature is sufficient when in combination with the completed highest test temperature expressed as a linear function that results in the desired Defined Life at the desired temperature class.

7A.4.3 For all three Procedures A, B and C, the Defined Life result shall be rounded down to the nearest 500 hour and the Thermal Endurance Rating assigned shall be expressed as Thermal Class / Hours (h). e.g. 130(B) / 1500h; 130(B) / 2000h; 130(B) / 2500h; 130(B) / 3000h: 130(B) / 3500h; 130(B) / 4000h; 130 (B) / 4500h; 130(B) / 5000h and etcetera for each higher thermal class 155(F), 180(H), 200(N); 220(R), 240(S).

MARKING

8 Details

8.1 An insulation system shall be legibly and permanently marked with the manufacturer's name, trade name, or trademark, and a distinctive catalog number or the equivalent.

Exception: The insulation system is not required to be marked when it is intended to be used in the manufacturer's end-use product, and when both the system and end-use product are available for examination at the same time and place.

8.2 When a manufacturer produces or assembles an insulation system at more than one factory, each finished system shall have a permanent, distinctive marking by which it shall be identified as the product of a particular factory.

SUPPLEMENT SA (NORMATIVE)
Substitutions or Modification to an Electrical Insulation System

INTRODUCTION

SA1 Scope

SA1.1 The requirements of this supplement cover the substitution and/or modification to an electrical insulation system established by a thermal aging test as described in Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA2 General

SA2.1 In an insulation system for which a temperature class has been established by test, substitution or modification of EIM and NIM components shall be evaluated and the necessity of additional testing shall be determined.

SA3 Non-Electrical Insulating Materials (NIM) Components

SA3.1 Substitution of an identical NIM component from an alternate supplier shall be investigated by subjecting samples to one or more short-term tests, such as qualitative infrared analysis, thermogravimetric analysis, dielectric strength, or other appropriate tests, to determine whether substitute materials are at least equivalent to the original materials. A chemically different material shall be subjected to an aging test as described in Section SA7, Insulation Systems – One Temperature Thermal Aging or to a chemical compatibility test as described in Section SA9, Sealed Tube Component Compatibility Test.

Exception: No additional testing is required for the substitution or addition of a thermal protection device such as a thermal cut-off or thermal fuse.

SA4 Magnet Wire and Winding Wire

SA4.1 General

SA4.1.1 One magnet wire is able to be substituted for another without regard for the build when, for any type of magnet wire as defined by NEMA MW 1000, it is the same as that used in the original insulation system.

Exception: The substitution of bondable magnet wires shall be evaluated to the requirements of SA4.3.

SA4.1.2 For a given NEMA MW 1000 type magnet wire, aluminum conductors are able to be substituted for copper.

SA4.1.3 For a given NEMA MW 1000 type magnet wire, the substitution of a copper conductor in an insulation system originally evaluated with aluminum conductors necessitates the creation of a new insulation system to be determined by an aging program in accordance with Section 7, Electrical Insulation Systems – Full Thermal Aging.

Exception: Substitution of NEMA MW 1000 type MW 37C may be substituted in an EIS thermally aged with NEMA MW 1000 type MW 35A magnet wire without the need for additional testing.

SA4.1.4 For a given enamel-coated magnet wire type, round and rectangular conductors are considered interchangeable.

SA4.1.5 See Annex A – Information for Magnet Wire Substitution, for specifications of various NEMA MW 1000 magnet wire types which are capable of being substituted for one another. Due to chemical differences, solderable polyester basecoat wires are not generically similar to non-solderable polyester basecoat wires and are not suitable for substitution into an EIS thermally aged with non-solderable polyester basecoat wire. However, non-solderable polyester basecoat wire may be substituted into an EIS thermally aged with solderable polyester basecoat magnet wire.

SA4.2 Non-bondable magnet wire

SA4.2.1 Regardless of the type of conductor metal, one non-bondable magnet wire is able to be substituted for another non-bondable magnet wire when the following conditions are met:

a) The wire's basecoat, by either qualitative infrared analysis or comparative chemical analysis, is determined to be generically similar to that used in the original insulation system;

b) The temperature class of the substitute magnet wire, as determined in accordance with IEC 60172 or ASTM D2307, is at least equivalent to the temperature class of magnet wire used in the original insulation system; and

c) Heat shock performance of the substitute magnet wire, as determined in SB4.5, is at least equivalent to the heat shock performance of the magnet wire used in the original insulation system.

SA4.2.2 A non-bondable Litz wire is able to be substituted for another non-bondable magnet wire when the following conditions are met:

a) The magnet wire used to make the Litz bundle complies with either SA4.1.1 or SA4.2.1 when compared to the magnet wire used in the original insulation system, and;

b) When the Litz bundle is being held together with anything other than a strand of the same magnet wire or the magnet wire topcoat, such as a filament, braid or serving, the compatibility of the bundling material with the rest of the insulation system has been investigated by an aging test per Section SA7, Insulation System – One Temperature Thermal Aging or a chemical compatibility test per Section SA9, Sealed Tube Chemical Compatibility Testing.

SA4.3 Bondable magnet wire

SA4.3.1 One bondable magnet wire is able to be substituted for another bondable magnet wire after evaluation per Section SA9, Sealed Tube Chemical Compatibility Testing, when both of the following conditions are met:

a) The magnet wire film coating, or combination of coatings, exclusive of the bondcoat, is capable of being substituted for the coating or coatings used in the original insulation system, as determined in accordance with SA4.2.1(a); and

b) The temperature class of the bondable magnet wire, as determined in accordance with IEC 60172 or ASTM D2307, is at least equivalent to the temperature class of the bondable magnet wire used in the original insulation system.

Exception: One bondable magnet wire is able to be substituted for another bondable magnet wire without testing per Section SA9, Sealed Tube Chemical Compatibility Testing, when the bondcoat, either by qualitative infrared analysis or comparative chemical analysis, is determined to be of the same basic composition to that used in the original insulation system.

SA4.3.2 A bondable magnet wire is able to be substituted for a non-bondable magnet wire after being tested per Section SA9, Sealed Tube Chemical Compatibility Testing, and test results evaluated to the requirements in SA9.6 for any unvarnished thermally aged insulation system, when both of the following conditions are met:

a) The magnet wire, exclusive of the bondcoat, is capable of being substituted for the magnet wire used in the original insulation system as determined in accordance with SA4.2.1(a) and (c); and

b) The temperature class of the bondable magnet wire, as determined in accordance with IEC 60172 or ASTM D2307, is not more than one temperature class below the temperature class of the non-bondable magnet wire used in the original insulation system.

SA4.3.3 Bondable magnet wire without a supplemental varnish treatment substituted for a varnished magnet wire necessitates the creation of a new insulation system to be determined by an aging program in accordance with Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA4.4 Non-enamel coated conductors

SA4.4.1 An insulating material wrapped around a bare conductor or an interleaved turn insulating material in a strip wound configuration is able to be incorporated into an insulation system when:

a) It is identical to the ground or interwinding insulation that was subjected to the aging per Section 7, Electrical Insulation Systems – Full Thermal Aging; and

b) Condition (1) or conditions (2) and (3) are met:

1) The use thickness is equal to or greater than the thickness employed in the thermal aging; or

2) The use thickness is such that the volts-per-unit thickness stress is not greater than the stress the material was subjected to during aging per Section 7, Electrical Insulation Systems – Full Thermal Aging, based on 120 V turn-to-turn stress; and

3) Insulation systems that employ the thickness reduction per item (2) shall utilize wrapped conductors in the appropriate thickness when modified by testing per Section SA9, Sealed Tube Chemical Compatibility Testing.

SA4.5 Non-enamel insulated winding wire

SA4.5.1 A winding created using a wire of a type not covered by NEMA MW 1000, such as filament wires, special transformer winding wires, appliance wiring materials, single- and multi-layer insulated winding wire shall be evaluated as part of a new insulation system by means of an aging program per Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA4.5.2 The full thermal aging program to evaluate a non-enamel insulated winding wire in an insulation system shall be conducted without additional electrical insulating material separating this wire from grounded metal or another winding if the wire will be used without additional electrical insulating material in the final product.

SA5 Varnish

SA5.1 Substitute varnish

SA5.1.1 For insulation systems that were originally evaluated with a varnish, the criteria in SA5.1.2 – SA5.1.8 shall be used in evaluating a substitute varnish.

SA5.1.2 When the substitute varnish complies with SC2.4, no further testing is required to make the substitution.

SA5.1.3 The temperature classes of both a substitute varnish and the varnish used in the originally evaluated insulation system shall be determined by analysis of the thermal aging data on enameled magnet wire from at least two of the tests specified in Table SC3.1. Data is valid only when the enameled magnet wire is generically and thermally identical to that in the insulation system. A single varnish is capable of having different temperature classes based upon the test method used.

Exception: No thermal comparisons are made between varnishes for use with filament winding wires and sheet materials used as turn insulation since these materials are not used in the determination of varnish classes. Substitute varnishes proposed for use in systems utilizing these winding materials shall comply with the requirements specified in Section SA9, Sealed Tube Chemical Compatibility Testing, or the requirements described in Section SA7, Insulation Systems – One Temperature Thermal Aging.

SA5.1.4 Only data resulting from the same test are to be compared as required by SA5.1.3, SA5.1.5 and SA5.1.6.

SA5.1.5 A substitute varnish having temperature classes equal to or greater than those of the varnish used in the originally evaluated insulation system shall be evaluated per the requirements in Section SA9, Sealed Tube Chemical Compatibility Testing, or per the requirements described in Section SA7, Insulation Systems – One Temperature Thermal Aging.

SA5.1.6 A substitute varnish having temperature classes for one or both tests not more than one class lower than those of the varnish used in the originally evaluated insulation system shall be evaluated per the requirements in Section SA9, Sealed Tube Chemical Compatibility Testing or per the requirements described in Section SA7, Insulation Systems – One Temperature Thermal Aging, when all of the following conditions are met:

a) The temperature class of the varnish/magnet wire coating combination resulting from the twisted pair aging test shall be no lower than that of the unvarnished magnet wire;

b) The twisted pair aging data to be compared shall be from magnet wires that are generically and thermally identical to those in the originally evaluated insulation system; and

c) Temperature classes to be compared shall be based on the correlation times specified in Table SC3.1.

SA5.1.7 A substitute varnish having temperature classes for one or both tests not more than one class lower than those of the varnish used in the originally evaluated insulation system where the temperature class of the varnish/magnet wire combination resulting from the twisted pair is lower than that of the unvarnished magnet wire, shall be evaluated per the requirements described in Section SA7, Insulation Systems – One Temperature Thermal Aging, when both of the following conditions are met:

a) The twisted pair aging data to be compared shall be from magnet wire coatings that are generically and thermally identical to those in the originally evaluated insulation system; and

b) Temperature classes to be compared shall be based on the correlation times specified in Table SC3.1.

SA5.1.8 A varnish not complying with the requirements in SA5.1.2 – SA5.1.7 shall be evaluated as a new insulation system, by means of an aging program as specified in Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA5.2 Addition of varnishes to systems originally evaluated without a varnish

SA5.2.1 The addition of a varnish to an insulation system which was originally evaluated without a varnish is permitted when all of the following criteria are met:

a) The varnish/enameled magnet wire combination must have been investigated per SC2.1 with the resulting twisted pair temperature class of the combination not more than one temperature class below the temperature class of the unvarnished magnet wire as tested in accordance with SB3.3; and

b) Chemical compatibility of the varnish with the entire system shall be determined by one of the following:

1) Section SA7, Insulation Systems – One Temperature Thermal Aging;

2) Section SA8, Insulation Systems –Two Temperature Thermal Aging; or

3) Section SA9, Sealed Tube Chemical Compatibility Testing.

SA5.2.2 Failure to comply with SA5.2.1 necessitates the creation of a new insulation system, and acceptability shall be determined by means of an aging of the varnished insulation system in accordance with Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA5.3 Modifying an EIS thermally aged with a varnish to an EIS thermally aged without a varnish

SA5.3.1 For EIS evaluated in accordance with Section 6, Electrical Insulation Systems – Full Thermal Aging that included a varnish as an EIM component shall be evaluated with Section SA7, Insulation Systems – One Temperature Thermal Aging test to change the EIM component varnish to a NIM component thereby establishing the EIS as thermally aged without a varnish.

SA5.3.2 An EIS that complies with SA5.3.1, shall be considered an EIS originally aged without a varnish and further varnish substitution shall use criteria in SA5.2 – Addition of varnishes to systems originally evaluated without a varnish.

SA6 Encapsulants, Ground, and Interwinding Insulation

SA6.1 Substitution or modification of encapsulants, ground, or interwinding insulations shall be required to comply with one of the requirements in SA6.2 – SA6.7.

SA6.2 Encapsulants, ground, or interwinding insulations that employ a base resin which is not generically similar to an encapsulant, ground, or interwinding insulation specified in an insulation system or which does not meet the criteria described in SA6.3 – SA6.7 shall be evaluated as a new insulation system by means of an aging program in accordance with Section 7, Electrical Insulation Systems – Full Thermal Aging.

SA6.3 Encapsulants, ground, or interwinding insulations that are identical to, except thinner than, encapsulants, ground, or interwinding insulations specified in a insulation system shall be evaluated for acceptance in the system based on an aging test per Section SA7, Insulation Systems – One Temperature Thermal Aging.

SA6.4 An encapsulant, ground, or interwinding insulation whose principal constituents (base resin, filler, reinforcement, flame retardant, heat stabilizer, and anti-oxidant) are found, based on documentation, to be identical in composition and proportion to those of an encapsulant, ground, or interwinding insulation presently specified in an insulation system shall be accepted in the system without additional tests when both the following conditions are met:

a) The assigned relative thermal indices (electrical and mechanical) and minimum thickness of the substitute material are equal to or greater than those of the presently specified material; and

b) The substitute material differs from the presently specified material only with respect to molecular weight, lubricant, nucleating agent, anti-static agent, colorant, particle size, or catalyst (that by definition is non-reacting).

Exception: A plastic material that is related to a currently specified encapsulant, ground or interwinding material that was originally investigated by testing per Section 7, Electrical Insulation Systems – Full Thermal Aging, shall be accepted in the system without test when the material is found to be in the same family based on documentation and complies with the polymer variation requirements specified in UL 746A or CSA C22.2 No. 0.17.

SA6.5 An encapsulant, ground, or interwinding insulation whose base resin, filler, reinforcement, and curing agent is shown, based on documentation, to be similar in generic type and proportion to those of an encapsulant, ground, or interwinding insulation presently specified in an insulation system and which differ from that material in other respects shall be evaluated for acceptance in the system on the basis of a thermal aging test of the insulation system per Section SA8, Insulation Systems – Two Temperature Thermal Aging, when the following conditions are met:

a) The assigned relative thermal indices (electrical and mechanical) and minimum thickness of the substitute material are equal to or greater than those of the presently specified material; and

b) The assigned relative thermal indices (electrical and mechanical) of the presently specified material were established based on the material's thermal aging, as opposed to generically assigned.

SA6.6 Ground or interwinding insulation supplied as a film and demonstrated to be polyethylene terephthalate by qualitative infrared analysis and whose source or grade designation differs from the polyethylene terephthalate ground or interwinding insulation originally investigated in an insulation system shall be accepted in the system without additional tests when the assigned electrical and mechanical relative thermal indices and minimum thickness are the same or higher than those of the original material.

SA6.7 Ground or interwinding insulation consisting of one or more layers of adhesive-coated tape made from a backing material which is identical to a ground or interwinding insulation material specified in an insulation system shall be accepted in the system when the following are met:

a) The tape is used in multiple layers such that the total thickness of the backing material (excluding adhesive) is not less than the thickness specified for the material in that system;

b) The thickness and identity of the backing material used to produce the tape is suitably documented; and

c) The compatibility of the adhesive with the rest of the insulation system has been investigated by an aging per Section SA7, Insulation Systems – One Temperature Thermal Aging or a chemical compatibility test per Section SA9, Sealed Tube Chemical Compatibility Testing.

SA6.8 When ground or interwinding insulation currently specified in the electrical insulation system is laminated with an additional material (e. g. plastic film or paper), the new composite material shall be accepted in the insulation system when (a) and (b), or (a) and (c), are met:

a) The thickness of the portion of the new composite material already specified for use as ground or interwinding insulation is not less than the thickness specified for that material in the system.

b) The material laminated to the ground or interwinding insulation material, and the laminating adhesive, are currently specified in the electrical insulation system.

c) The compatibility of the new composite material, including the laminating adhesive, with the rest of the insulation system has been investigated by an aging per Section SA7, Insulation Systems – One Temperature Thermal Aging or a chemical compatibility test per Section SA9, Sealed Tube Chemical Compatibility Testing.

SA6.9 The introduction of encapsulant material to an open-type system (non-encapsulated) necessitates the creation of a new insulation system to be determined by an aging program per Section 7, Electrical Insulation Systems – Full Thermal Aging.

PERFORMANCE TESTS

SA7 Insulation Systems – One Temperature Thermal Aging

SA7.1 General

SA7.1.1 A one temperature thermal aging program is able to be used instead of full thermal aging in order to evaluate certain system modifications, such as the following:

a) As an alternative to a chemical compatibility test when adding NIM components.

b) Reduction of thickness of any EIM in the EIS, including reduction down to a zero level.

c) Modifying EIS thermally aged with a varnish (EIM) to an EIS thermally aged without a varnish (NIM).

d) Qualification of an alternate varnish/magnet wire combination whose thermal indices are no more than one temperature class lower than those of the varnish used in the originally evaluated system, and whose twisted pair thermal indices are less than that of the unvarnished magnet wire. See Section SA5.

e) Evaluation of a lead wire which is rated more than 5°C (9°F) below the system temperature class rating whereby one or both of the following conditions are met:

1) The lead wire is in direct contact with the windings or enters the outer wrap.

2) The rated temperature of the lead wire is below that referenced in Table 6.1.

SA7.2 Samples, exposures, and tests

SA7.2.1 Representative samples of the unmodified (original) and modified systems are to be constructed, thermally aged, and tested in accordance with the criteria in Section 7, Electrical Insulation Systems – Full Thermal Aging, with the following exceptions:

a) The unmodified system represents the reference system, and the modified system represents the candidate system.

b) The reference and candidate systems shall be concurrently tested at one temperature only. This temperature shall be the same for both systems.

c) The test temperature specified is to be the temperature from the full thermal aging program which resulted in a log-average life closest to 1,000 h (usually the second highest temperature).

d) When original materials are no longer available, they shall be deleted or substituted with similar materials when agreed to by all interested parties.

e) When evaluating an alternate lead wire which is to be employed as described in SA7.1.1(e)(1), samples shall be constructed such that the lead wire is in direct contact with the conductor windings, except the lead wire is not to be energized.

SA7.3 Analysis and evaluation

SA7.3.1 It shall be assumed that the regression line slope of the candidate insulation system is identical to the regression slope of the reference system based on its original full thermal aging, and that the equations differ only in the value of the ordinate intercept.

SA7.3.2 The correlation time shall be established by combining the regression slope of the reference system's original aging with the newly generated time-temperature data point for the reference system, and then evaluating the resulting equation at the original apparent thermal index temperature of the reference system.

SA7.3.3 The apparent thermal index temperature of the candidate system shall be established by combining the reference system's original regression slope with the newly generated time-temperature data point for the candidate system, and then evaluating the resulting equation at the correlation time established above.

SA7.3.4 The following steps shall be followed to determine the correlation time and the apparent thermal index temperature of the candidate insulation system:

a) Determine the correlation time t_c in hours as given by:

$$t_c = t_u \exp_{10} \frac{M}{T_a + 273.15} - \frac{M}{T_u + 273.15}$$

In which:

M is the slope of the original (reference) system regression equation

T_a is the apparent thermal index temperature in °C of the original (reference) system

T_u is the aging temperature in °C of the reference (unmodified) system

t_u is the time in hours to reach end of test-life for the reference (unmodified) system

b) Determine the apparent thermal index temperature T in °C of the candidate insulation system from:

$$T = \frac{M}{\log_{10}\frac{t_c}{t_m} + \frac{M}{T_m + 273.15}} - 273.15$$

In which:

M is the slope of the original (reference) system regression equation

t_c is the correlation time in hours, determined in (a)

T_m is the aging temperature in °C of the candidate (modified) system

t_m is the time in hours to reach end of test-life for the candidate (modified) system

SA7.3.5 In order for the candidate (modified) insulation system evaluated for the purpose of evaluating chemical changes to be assigned the same insulation system temperature class rating as the reference (unmodified) system, the apparent thermal index determined for the modified insulation system shall be within ±5°C (±9°F) of the apparent thermal index determined for the original insulation system. When this temperature difference is greater than ±5°C (±9°F), then an aging as specified in Section SA8, Insulation Systems – Two Temperature Thermal Aging or an aging as specified in Section 7, Electrical Insulation Systems – Full Thermal Aging shall be conducted to confirm the temperature class.

SA7.3.6 In order for the candidate (modified) insulation system evaluated for the purpose of evaluating EIM component insulation thickness reductions or modifying an EIS varnish EIM to NIM component to be assigned the same insulation system temperature class rating as the reference (unmodified) system, the apparent thermal index determined for the modified insulation system shall be either within ±5°C (±9°F) of the apparent thermal index determined for the original insulation system or be the same insulation system temperature class of the original insulation system. When the results do not fall within ±5° C (±9° F) or within the same insulation temperature class, an aging as specified in Section SA8, Insulation Systems – Two Temperature Thermal Aging or an aging as specified in Section 7, Electrical Insulation Systems – Full Thermal Aging shall be conducted to confirm the temperature class.

SA8 Insulation Systems – Two Temperature Thermal Aging

SA8.1 General

SA8.1.1 A two-temperature thermal aging program is able to be used instead of full thermal aging in order to evaluate certain system modifications. These modifications are the same as those referenced in Section SA7, Insulation Systems – One Temperature Thermal Aging and additionally are able to include the encapsulant, ground, or interwinding material substitutions as specified in SA6.5.

SA8.2 Samples, exposures, and tests

SA8.2.1 Representative samples of the unmodified (original) and modified systems shall be constructed, thermally aged, and tested in accordance with the criteria for full thermal aging per Section 7, Electrical Insulation Systems – Full Thermal Aging, with the following exceptions:

a) The unmodified system represents the reference system, and the modified system represents the candidate system.

b) The reference and candidate systems shall be concurrently tested at two temperatures only. These temperatures shall be the same for both systems.

c) The test temperatures specified shall be any two which were employed in the full thermal aging program (usually the two highest temperatures).

d) When original materials are no longer available, they shall be deleted or substituted with similar materials when agreed to by all interested parties.

SA8.3 Analysis and evaluation

SA8.3.1 The analysis and evaluation for a two point thermal aging is identical to that of a one point thermal aging, as specified in SA7.3, except that the two time-temperature data points determined for each reference and candidate system shall be expressed as a single arithmetic mean time-temperature data point.

SA8.3.2 Once the mean time-temperature data points have been determined, the two-temperature analysis and evaluation reduces to that of the one-temperature aging.

SA8.3.3 The arithmetic mean time t(ave) in hours for both the reference and candidate systems shall be determined by:

$$t(ave) = \sqrt{t_1 t_2}$$

In which:

t_1, t_2 is the corresponding time in hours to reach end of test-life

SA8.3.4 The following steps shall be followed to determine the arithmetic mean temperature T(ave) in °C for both the reference and candidate systems:

a) Determine the arithmetic mean temperature T′(ave) in Kelvin as given by:

$$T'(ave) = \frac{2T_1'T_2'}{T_1' + T_2'}$$

In which:

T_1', T_2' is the corresponding aging temperature in K

T ' (K) is T (°C) + 273.15

b) Determine the arithmetic mean temperature T(ave) in °C by:

$$T(ave) = T'(ave) - 273.15$$

SA8.3.5 The correlation time t_c in hours shall be determined by substituting t(ave) and T(ave) for the reference system into the equation specified in SA7.3.4(a) where t(ave) is substituted for t_u and T(ave) is substituted for T_u.

SA8.3.6 The apparent thermal index T in °C of the candidate system shall be determined by substituting t(ave) and T(ave) for the candidate system into the equation specified in SA7.3.4(b) where t(ave) is substituted for t_m and T(ave) is substituted for T_m.

SA8.3.7 In order for the candidate (modified) insulation system evaluated for the purpose of evaluating chemical changes to be assigned the same insulation system temperature class rating as the reference (unmodified) system, the apparent thermal index determined for the modified insulation system shall be within ±5°C (±9°F) of the original apparent thermal index determined for the reference system. When this temperature difference is greater than ±5°C (±9°F), then an aging as specified in Section 7, Electrical Insulation Systems – Full Thermal Aging shall be conducted to determine the temperature class.

SA8.3.8 In order for the candidate (modified) insulation system evaluated for the purpose of evaluating EIM component thickness reductions to be assigned the same insulation system temperature class rating as the reference (unmodified) system, the apparent thermal index determined for the modified insulation system shall be either within ±5°C (± 9°F) of the apparent thermal index determined for the original insulation system or be the same insulation system temperature class of the original insulation system. When the results do not fall within ±5°C (±9°F) or within the same insulation temperature class, an aging as specified in Section 7, Electrical Insulation Systems – Full Thermal Aging shall be conducted to determine the temperature class.

SA9 Sealed Tube Chemical Compatibility Test

SA9.1 General

SA9.1.1 The test method for conducting Sealed Tube Tests shall be in accordance with ASTM D5642, as qualified below.

SA9.2 Glossary

SA9.2.1 BASE EIS – The combination of materials/components subjected to Section 7 – Electrical Insulation Systems – Full Thermal Aging test. These are the items included in the reference tube, see SA9.3.1(a).

SA9.2.2 EXPANDED EIS – The combination of materials/components subjected to Section 7 – Electrical Insulation Systems – Full Thermal Aging and Section SA9 – Sealed Tube Chemical Compatiblity Test. These are the items included in the Substitute Tube, see SA9.3.1(b).

SA9.2.3 LOAD LIST – The list of materials/components that need to be included in the Substitute Tube that are intended to be added to the base EIS to create the expanded EIS.

SA9.2.4 VARNISH – Solvent based liquid insulator.

SA9.2.5 IMPREGNATING RESIN – Non-solvent based liquid insulator.

SA9.3 Samples

SA9.3.1 In ASTM D5642, 7.1 shall be interpreted as follows:

a) Reference Tube – The tube is to contain only materials that were originally evaluated for the insulation system. When the original materials are no longer available, they shall either be deleted or substituted with materials that have been demonstrated to be equivalent in both composition and performance to the original materials, as agreed to by interested parties. See SA2.1 and SA4 of this Standard for criteria that shall be used to determine equivalency.